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An overview of the 'Aryabhata' project

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Abstract. *Aryabhata*, India's first satellite, was successfully launched into a near-earth orbit on 19 April 1975, from a USSR Cosmodrome. The primary objective of *Aryabhata* was to establish the indigenous capability in satellite technology. *Aryabhata*, weighing 358 kg, was quasispherical in shape, and had body-mounted solar cells and Ni-Cd chemical batteries as primary power sources. Other features of the spacecraft include power control systems, passive thermal control system, PCM/FM/PM telemetry system transmitting data at 256 bits/s in real time and 2560 bits/s in the stored mode, PDM/AM/AM telecommand system, cold gas spin stabilisation system with nutation damper and a number of sensors. The satellite also included three scientific experiments—one on x-ray astronomy, the second for observing solar neutrons and gamma rays and the third on aeronomy. The present paper gives an overview of the basic features of the satellite, associated ground stations and a brief account of the fabrication, testing and (in-orbit) performance of the satellite. Results of some of the technological experiments carried out in *Aryabhata* are also briefly described.

Keywords. *Aryabhata*; satellite technology; satellite design; satellite qualification; satellite performance.

1. Introduction

The remarkable advances in space science and technology during the last two decades have unambiguously demonstrated that it is possible to harness this technology for developmental purposes, particularly in developing countries. The direct benefits of space technology in communication, remote sensing, geodesy, navigation, oceanography, minerology and even in geography have now been well established. The most remarkable feature of satellite technology is its ability to obtain an instantaneous global view of large continents and land masses. With near-earth, polar-orbiting satellites carrying infrared and visual camera systems, it is possible to obtain high resolution global pictures for surveying natural wealth and resources in agriculture, forestry, hydrology, oceanography and geology so as to facilitate the optimal utilisation of these resources. Geostationary satellites provide a unique means of instantaneous communication and TV transmission throughout the country. For a developing country with a large rural population, this aspect of space technology has, for the first time, provided the capability of utilising the most powerful audiovisual media for educational purposes, for improving agricultural practices and for providing information on health, hygiene and family planning. Also from the large global coverage made possible through geostationary satellites, reliable advance weather prediction is now well within the practical reach of nations. The possibility of economically producing exotic materials and medicines in space and even harnessing large scale solar power using this technology seems to be a matter of time.

Realising the immense potential of this technology for providing a quantum jump in national development, the Indian Space Research Organisation (ISRO) initiated research in this area in 1963. What began as a modest rocket sounding programme, for conducting scientific experiments for the study of the upper atmosphere and ionosphere, rapidly grew to encompass application areas which could make unique contributions to national development.

Commensurate with the long term goals involving the exploitation and diffusion of the potentialities of space research into the mainstream of national development, ISRO has embarked upon a systematic programme for the setting up of a full-fledged indigenous base for the design, fabrication, qualification and in-orbit operation of artificial earth satellites for a variety of scientific and application missions. As a first step in this direction, ISRO signed an agreement with the USSR Academy of Sciences in 1972 for launching an Indian-built technological satellite from a Soviet Cosmodrome, using an Intercosmos rocket carrier, in a time frame of 2–3 years. As a follow-up of this agreement, the ISRO Satellite Systems Project was established at Peenya village at the outskirts of Bangalore, with a team of about 200 scientists and engineers. The successful launching on 19 April 1975 of *Aryabhata*, India's first satellite, was thus the first major step at harnessing the potential of this technology towards our long term goals in space research. The excellent performance of this satellite during the last two years has firmly established our capability for designing, fabricating and launching near-earth orbiting satellites in the weight class of 300-400 kg. In addition, this project has created a nucleus of expert scientists and engineers around whom the future activities can be planned.

2. Objectives of the 'Aryabhata' mission

The primary objectives of the *Aryabhata* mission were:

(i) indigenous design and fabrication of as paceworthy system and evaluation of its performance in orbit;
(ii) evolving the methodology of conducting a series of complex operations on the satellite in its orbital phase;
(iii) setting up the necessary ground-based receiving, transmitting andt racking systems; and
(iv) establishing the relevant infrastructure for the fabrication, testing and qualification of such sophisticated spacecraft systems.

In view of the considerations that such an exercise could also provide Indian scientists with an opportunity to conduct investigations in space sciences, it was decided to include suitable payloads for studies in x-ray astronomy, aeronomy and solar neutron and gamma rays.

3. Major segments of the project

These are, broadly, the space segment, the ground segment including mission planning and operations, infrastructure development and Soviet interface.

3.1 *Space segment*

3.1a *Description of the satellite*

The satellite is quasispherical in shape, with 26 flat faces, and weighs 358 kg. It has an equivalent diameter of 1·59 m in the equatorial plane and a height of 1·19 m. A passive thermal contro system employing paints of requisite emissivity-to-absorptivity ratio enables the maintenance of the internal temperature between 0 and 40°C for the reliable operation of the electronic systems. For powering the various subsystems, the spacecraft has a power system configured around body-mounted silicon solar panels and rechargeable Ni-Cd chemical batteries.

The quasispherical shape of the satellite was essentially dictated by the requirements of obtaining maximum surface area for deriving electrical power from the body-mounted solar cells commensurate with minimal fluctuations when the satellite is stabilised in the spinning mode. Further, an axisymmetrical shape provides the simplest configuration which can provide a uniform temperature distribution within a spinning satellite. Additionally, the choice of the physical shape of the satellite has to conform to the dynamic envelope of the rocket vehicle. Thus, the shape shown in figure 1, (plate 1) was arrived at.

The temperature distribution within any satellite in space is primarily dictated by the heat inputs due to solar radiation, the reflected radiation from the earth and the power dissipation from various subsystems within the satellite on the one hand and heat loss from the satellite into space on the other. Detailed calculations, performed using multinodal analysis, show that the temperature on the outside surface of the satellite can go as high as 100 to 150°C when the satellite is on the sun-lit side and can go down to almost −80°C when it is on the night side of the earth, depending on the position of the sun and the orientation of spin axis of the satellite in space. Reliable operation of the satellite demands that the thermal distribution inside the satellite where the electronic subsystems are housed should be controlled within reasonable limits. The temperature inside the spacecraft is maintained between 0 and 40°C using passive thermal control techniques. These involve coating the electronic boxes and satellite surface with suitable paints, and carrying out appropriate surface treatment such as polishing, anodizing etc., to achieve the requisite emissivity and absorptivity parameters. The experimental verification of the thermal control calculations was carried out by subjecting a half-scale size thermal model of the satellite to various simulated heat inputs within a thermovacuum chamber.

As mentioned earlier, the electrical power is generated from body-mounted solar panels consisting of silicon n/p cells, over a total surface area of 36,800 cm^2. Ni-Cd chemical battery of 10 A hr capacity provide power to the satellite during the orbital night in addition to sharing the load with the solar cells during peak demands. Out of the average raw power of 46 W generated by the solar panels under sunlit conditions, about 23 W are used for charging the chemical batteries, the rest being available for operating various electronic systems onboard. Conditioned power is supplied to various loads at four buss voltages, viz., $+14$, $+9$, -14 and -9 V, regulated to better than 1 %. The positive buss voltages are provided directly through high efficiency switching regulators and the negative buss voltages are generated using d.c.-d.c. converters followed by switching regulators. Vital systems like tape recorders and the telemetry transmitters are provided with independent supply units. Besides, the power system includes the following auxiliary protective units: a limiter to check

the overshoot of the solar array voltage, current sensors, circuit for regulating the charging process for the battery, a control unit (controls the raw power to regulators, the charge, trickle charge and discharge of the battery and emergency operations) and fail-safe devices between regulators and load to safeguard against short or overload.

In order to retrieve and process the data on the performance, parameters of the different satellite systems such as power, attitude, thermal control and communications, as well as the information gathered by the scientific experiments, a PCM/FM/PM downlink is employed. The PCM system has been chosen primarily because of its superior information efficiency, i.e., use of relatively small bandwidth and power, because there are as many as 91 parameters to be monitored onboard *Aryabhata* with typical time resolutions ranging from 250 ms to 4 s. Further, an intermediate FM sub-carrier of frequency 22 kHz is employed to enable the use of the entire uplink/downlink configuration in a transponder mode.

The data gathered by the satellite are transmitted in real time through this telemetry system, at a rate of 256 bits/s. Since the radio visibility time over a receiving station can vary from 0 to 12 min, an average time of 4 min has been allotted for data transmission. The total data received in the real time mode are thus only a small portion of the data collected over the complete orbit period and hence an onboard tape recorder has been incorporated for storing information during the period when the satellite is not in the radio-visibility and transmit the same when it becomes visible over a ground station. The stored data are then played back, on command, at 2560 bits/s. For improved reliability, a redundant tape recorder is available which can be selected by command. The carrier frequency for the downlink is 137·44 MHz.

A PDM/AM/AM telecommand system consisting of a 1 kW transmitter and an appropriate encoder on ground and a receiver with the corresponding decoder onboard constitutes the uplink of the satellite. This system has been chosen so as to be compatible with the standard NASA mini track network, so that in case of emergency, one or more of these stations could be made use of. Various control instructions such as energising the different subsystems, switching over to redundant systems, playback of the tape recorder etc., can be sent to the satellite through the command link, by selecting the appropriate command out of a total of 35 commands available. Redundant units are available for both the receiver and the decoder onboard to assure a reliable uplink for the satellite. All the command operations are monitored through telemetry. The carrier frequency for the uplink is 148·25 MHz. The telemetry transmitters and telecommand receivers are both coupled to a command antenna system via a hybrid coupler unit that isolates the uplink and downlink. With the spacecraft weight constraints, no separate onboard tracking package could be placed for tracking the satellite. However, with the available onboard communication packages involving both receiver and transmit chains, tone ranging, Doppler and interferometry systems could be suitably configured for obtaining range, range rate and positional information of the satellite. Tone ranging system uses the transponder configuration wherein tones having frequency ranges 32, 160, 800 and 4000 hZ are sent to the satellite by modulating the telecommand transmitter. The received tones from the onboard command receiver are used to modulate the telemetry transmitter and received on ground to calculate the range of the satellite. Doppler and interferometry systems use the telemetry transmitter carrier frequency as the beacon frequency for tracking purposes.

Attitude stabilisation of the satellite in orbit is realised in the simplest possible mode by spinning it around the axis of maximum moment of inertia. The spin-up operation is done by cold gas jets in a single-shot, blow-down mode, the available gas in each bottle being capable of imparting a spin rate of about 60 rev/min to the satellite. A fluid-in-tube nutation damper enables one to arrest the precession arising out of the disturbances during the separation of the satellite from the rocket and subsequent spin-up operations. The system is designed to limit the coning angle to better than 0·1°. Information on the aspect and the spin of the satellite is derived by a set of triaxial magnetometers and digital sun sensors. The sensor system can yield an aspect accuracy better than 1°. Calculations indicated that the desirable accuracy in precession can be maintained even if the spin rate is as low as 5 rev/min. The solar sensor also provides an inhibit signal to prevent accidental release of gas from the gas bottles, if the spin rate is greater than 20 rev/min.

The satellite has, onboard, three scientific experiments for investigations in the areas of x-ray astronomy, solar neutrons and gamma rays and aeronomy. The x-ray astronomy experiment is designed for the investigations of celestial x-ray sources primarily in relation to their time variation effects in energy range of 2·5–150 keV. A proportional counter telescope of 15 cm^2 effective area and a NaI (Tl) scintillator telescope with an effective area of 11·4 cm^2 are employed to enable observations in the pointed and scan modes, along and perpendicular to the spin axis respectively. The solar neutron and gamma ray experiment is primarily designed to detect high energy neutrons (10–500 MeV) and gamma rays (0·2–20 MeV) from the sun both during quiet times and flares. The basic detector is a 12·5 cm diameter CsI (Tl) scintillator of 1·25 cm thickness. The aeronomy experimental package consists of a retarded potential analyser for the detection of suprathermal electrons upto 100 eV and two UV chambers to measure the intensities of Lyman alpha (1216 Å) and oxygen line (1304 Å) at *F*-region altitudes of the earth's ionosphere.

3·1b *Fabrication, testing and quality assurance aspects*

(i) In order to ensure the highest reliability of the final product, development of the spacecraft was carried out through the fabrication and testing of a series of models. The first step was the design and fabrication of a bread-board model where most of the electronics subsystems were tested using a hybrid combination of Indian and imported components. The subsystems, including telemetry, telecommand and communication units, were integrated inside a satellite structure roughly half the size of the final version and tested out on a balloon at 25 km altitude on 5 May 1973. The x-ray astronomy payload, magnetometers and sun sensors were also similarly tested. The communication link was tested to a distance of 400 km by this method.

(ii) A one-to-one mechanical mock-up model comprising the structure and the various subsystems was fabricated to evaluate the mechanical design by carrying out accleration, shock and vibration tests corresponding to the levels that will be encountered during the launch phase. These tests were completed in February 1974. The same model was also taken to Cosmodrome in USSR during April 1974 and mated with the actual Soviet rocket carrier to check compatibility. Simultaneously, work on building a pre-prototype model was also completed to understand the problems related to mechanical assembly and electrical integration.

(iii) A pre-prototype version of the complete satellite was fabricated to evaluate the

total electrical system compatibility; this version differed from the prototype and flight models in the use of non-space-qualified components. Therefore, the full-fledged environmental tests were not carried out on this model. The subsystems, however, were subjected to thermal cycling, a limited vacuum check, vibration and acceleration tests.

(iv) The electrical prototype of the satellite, which was a replica of the flight model, was fabricated with the inputs from the earlier models and tested at Peenya during June-November 1974. The tests included qualification in thermo-vacuum chamber, vibration and shock tests as well as magnetic cleanliness tests at subsystems level, besides integrated two-axis vibration tests. The same model was also used to conduct compatibility tests with the ground station at SHAR. The satellite model was taken up in a helicopter over SHAR (figure 2, plate 2) during January 1975, kept almost stationary at various distances and altitudes from the ground station and the two-way communication link between the satellite and the ground telemetry station was checked under simulated power levels of the transmitters.

(v) The final phase was the fabrication of two flight models, one serving as a standby for any last minute eventuality. The complete integration and testing of the flight model-I of the satellite were completed during January-March 1975.

In the case of prototype and flight models, space-qualified components were used. These high reliability components were specifically selected from the preferred part list of NASA which carry approval for use in space missions. Some of the passive components like resistors and capacitors, and active devices like transistors that were not available in high reliability versions were specially screened at the Controllerate of Inspection Electronics (CIL), Bangalore. Special fabrication, inspection and

Table 1. Screening tests for electronic components

A = Applicable
NA = Not applicable

Tests	Electronic component				
	Semi-conductors	Capacitors (fixed/ variable	Resistors (fixed/ variable	Ther-mistors	Coils/Induc-tors/Trans-formers
Visual & mechanical inspection tests	A	A	A	A	A
Initial parameter measurements	A	A	A	A	A
Radiographic inspection (x-ray)	NA	A	A	NA	NA
Seal test	A	A	A	NA	A
Temperature cycling	A	A	A	A	NA
Thermal shock	A	NA	A	NA	A
Burn-in or bake test	A	NA	A	A	NA
High temperature bake	A	NA	NA	A	NA
Voltage conditioning	NA	A	NA	NA	NA
High temperature reverse bias (HTRB)	A	NA	NA	NA	NA
Acceleration	A	NA	NA	NA	NA
Mechanical shock	A	NA	NA	NA	NA
Final parameter measurements	A	A	A	A	A

Table 2. Environmental test specifications for onboard electronic subsystems

Satellite model	Environmental test				
	Hot & cold (storage)	Hot & cold (soak)	Vibration (X, Y, Z)	Shock	Thermal vacuum
Pre-prototype Prototype	Hot : 60° ± 1°C Cold : 30° ± 1°C Duration : 6 hr Pull-down time : 2 hr	Hot : 55° ± 1°C Cold : 15° + 1°C Duration : 6 hr Pull-down time : 2 hr	Sweep rate : 0·25 oct/min Frequeney : 3–2500 Hz Amplitude (g) : 0·3–15	Acc : 20 G Duration : 10 ms Pulse : Square No. of shocks : 18	High temperature: 50°±1°C Low temperature: −10°±1°C Duration : 24 hr Pressure : 10^{-5} torr
Flight	NA	Hot : 40° ± 1°C Cold : 0° ± 1°C Duration : 6 hr Pull-down time : 1 hr	Frequency : 30–60 hZ Amplitude (g) : 5 Duration : 5 min	NA	High temperature: 40° ± 1°C Low temperature : 0° ± 1°C Duration : 24 hr Pressure : 10^{-5} torr

NA = Not applicable

approval procedures were evolved to ensure the overall reliability of the spacecraft. These were strictly adhered to at both subsystem and system levels. The environmental specification for onboard electronic subsystems are listed in table 1. The screening tests for electronic components are listed in table 2.

3.2 *Ground segment and mission operation*

3.2a *Ground stations*

The primary ground station for receiving data and commanding the satellite was located at Sriharikota (SHAR) near Madras. The station consisted of a fully steerable yagi antenna array (figure 2, plate 2) and a complete set-up for receiving the data from the satellite, displaying them, and conducting preliminary analysis to quickly determine the state of the health of the satellite. Besides, facilities to command the satellite from the ground were established. In addition, a tracking network consisting of a Doppler, interferometry and tone ranging system was also installed at SHAR, to derive the orbital parameters of the satellite correct to 1° in elevation and azimuth and $\pm$ 500 m in range. The functioning of the entire ground station was also tested using a helicopter-borne satellite model and simulating the transmitter power levels for the maximum range that the satellite will have during its orbit, to ensure that the ground station can receive the telemetered data from the satellite and send commands to the satellite at any distance above 10° elevation.

The ground station at Moscow belonging to the USSR Academy of Sciences received additional data from the satellite thus enhancing the total data coverage from the satellite. A telecommand station built at the ISRO Satellite Centre, Bangalore was also installed at Moscow for commanding the satellite from Moscow to get both real time and stored data. To further increase the data coverage, the French Space Agency, CNES, provided real-time telemetry reception and tracking of the satellite in the initial phase. The optical Baker-Nunn camera at Nainital observatory was also used for optical tracking of *Aryabhata*.

3.2b *Mission operations*

A Mission Operations and Control Centre was set up at Peenya, Bangalore, to coordinate the commanding as well as data-gathering programme from various ground stations. From this Centre, the information regarding the radio-visibility of the satellite for the ground stations was transmitted. Both the quick-look data which provided information on the health of the satellite almost on real time basis as well as comprehensive data were sent from each of the ground stations to the control centre at Bangalore. The control centre performed the necessary analysis and decided on the appropriate commands to be executed for the subsequent passes over the ground stations. Detailed data processing and conditioning for further analysis were also carried out at Bangalore and transmitted to various scientists.

3.3. *Infrastructure*

The work of setting up the necessary infrastructure for fabricating and testing various

subsystems of the satellite was taken up immediately after the project was set up. These facilities included highly sophisticated electronics laboratories, a clean room for the final assembly of the satellite, thermal laboratories, control and stabilisation laboratories, antenna testing facilities, a small workshop and a draughting section. In addition to these general facilities, a few specialised facilities were also set up. These included a dynamic balancing machine for balancing the fully integrated satellite, equipment for measuring the centre of gravity and moments of inertia of the satellite, and a space simulation or thermo-vacuum chamber, capable of simulating space environmental conditions such as temperature ranging from $-100°C$ to $+100°C$ at a pressure of 10^{-6} torr. This thermovacuum chamber was extensively used to test and qualify the different satellite subsystems at various stages of the developmental programme.

4. Pre-launch and launch aspects

After complete integration and testing at Bangalore, the fully integrated satellite was transported to the USSR Cosmodrome in a specially qualified 'shock-proof' container. The satellite inside the container was isolated with helical springs to dampen the mechanical shock and vibration and the container design was qualified by actual measurements during transportation over typical roads to ensure that the container was adequately safe to carry the satellite. At the Cosmodrome, the satellite was disassembled into its three main parts — bottom shell, deck plate with instrumentation and top shell (figure 3, plate 3). These were physically inspected and then electrically tested with the entire check-out system. After this the satellite was integrated once again, and a thorough check was conducted on the integrated satellite, both prior to and after mating with the rocket carrier.

Results of all the tests and the state of readiness of the satellite as well as the rocket were critically examined by a specially constituted launch commission, before fixing the date and time of launch. The readiness of the ground stations at SHAR, Moscow and Bangalore was checked, round the clock, through the dedicated communication link specially set up for this purpose between the Cosmodrome, Moscow ground station, SHAR ground station and the Mission Control Centre at Bangalore.

Aryabhata was successfully launched into a near-earth orbit at 1300 hr IST, on 19 April 1975. The orbital parameters immediately after the injection were apogee height 620 km, perigee height 562 km, and inclination 50·7°.

5. Orbital performance

Aryabhata was controlled during the initial phase from the ground station at Bears Lake, USSR, and during the normal phase from the SHAR ground station.

The satellite was powered immediately after its separation from the rocket, about 30 min after the launch, as could be seen from the telemetry signals received at SHAR for the first time during orbit 2. However it was found that (i) the satellite was tumbling at a rate of about 0·3° per second instead of spinning, and (ii) ± 9 V was not reaching the aeronomy experiment. All other subsystems, including power, telecommand, telemetry, communication, attitude sensors, thermal control system

and the scientific experiments, were functioning normally. In spite of the fact that the satellite was tumbling, the temperature of various subsystems was found to be within the expected limits, thus proving the excellent performance of the thermal control system.

Satisfactory signals were received from the satellite till orbit 17 after which some problems like sudden drop in the signals and non-synchronisation of telemetry frames were noticed. After carrying out some command operations to understand the above problems, it was observed during orbit 41 that +9 V regulator output supplying power to the three scientific experiments, was absent. All other power lines were working normally. It was then decided to switch off the three scientific experiments through ground command and make the satellite technologically functional. In orbit 45, a spin command was sent from the ground and the satellite was spin-stabilised at 50 rev/min.

After switching off the experiments, regular operation of the satellite was carried out for the reception of real-time and play-back data. Analysis of both quick-look and complete data was conducted to verify the performance of the onboard technological subsystems. A brief summary of the performance of various subsystems follows.

(i) The telemetry downlink functioned very well both in real-time and play-back modes. The received ground signal strength on an average was always more than −125 dBW which provided a good signal/noise ratio for interruption-free data acquisition. The frequency stability of the onboard transmitter was observed to be 0·00015%. The observed bit error rates during both the play-back and real-time mode were around 0·047% including the ground station instrumentation errors.

(ii) Consistent and reliable operation of telecommand uplink was established by successful execution of ground commands. The worst case onboard signal strength was observed to be −86 dBM, which was consistent with design specifications. The capability of execution of commands even at very low elevations provided a greater operation manoeuvre period over each pass.

(iii) The state vector information (initial conditions) of one orbit per week received from USSR was mainly used for generating target indications. The range and range-rate data received from SHAR were found to be offset by ± 5 km and ± 25 ms when compared to the best predictions. They were quite accurate to do the necessary orbital analysis and updatings and also gave confidence to generate target indication independently.

(iv) The performance of the thermal control system was quite satisfactory. All the electronic subsystems were kept within the desired temperature limits. The thermal control system performance characteristics for battery and transmitter are given in figure 4.

(v) Even though the actual theoretical estimates showed that the time constant of the decay could be about 220 days based on the calculations of eddy current losses in the conducting parts of the satellite, for the initial design the value of about 22·4 days was used based on the actual observations on ‘Cosmos’ satellites of roughly the same dimension as *Aryabhata*. Due to the extreme care taken in using non-magnetic materials on the spacecraft, actual

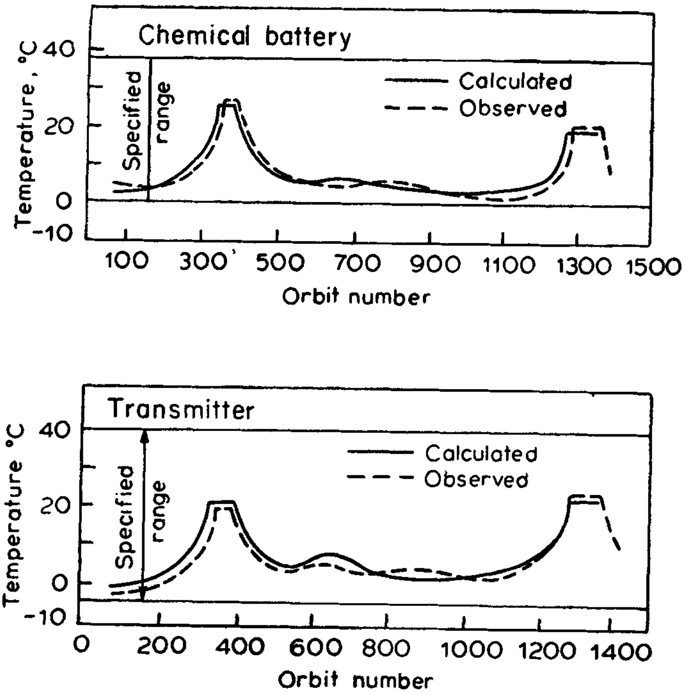

Figure 4. Inflight thermal control performance on *Aryabhata*

observations after the *Aryabhata* launch have shown that the decay constant is quite large, of the order of 150 days which has been responsible for the extension of the useful life-time of *Aryabhata* well beyond the original estimate of 6 months.

In addition to the regular operations of the satellite, a number of technological experiments were also carried out with a view to study the feasibility of using a space platform for relaying different types of complex data for various practical applications.

These technological experiments were essentially based on the use of the onboard telecommand receiver and transmitter in the transponder mode for transmitting data from one station to another through the satellite. In the first instance, a voice transmission experiment was performed wherein recorded speech was transmitted from SHAR and received at Bangalore via *Aryabhata*. The quality of the voice reception was very good. Subsequently, electrocardiogram (ECG) signals were similarly transmitted from SHAR and received at Bangalore via *Aryabhata*. The results were quite encouraging and demonstrated the feasibility of extending medical help to remote areas through the use of satellites.

The third experiment involved the transmission of weather data like temperature, wind speed, wind direction etc., from a standard data collection platform through the satellite. The data collection platform was set up at Sriharikota through the assistance of the India Meteorological Department (IMD), Poona. The experiment was conducted successfully and the results were found to be well within the limits of

accuracy required for meteorological purposes. The experience gained through this experiment will be valuable for future programmes in designing operational satellites for gathering meteorological data from remotely located data collection platforms.

6. Concluding remarks

This first Indian satellite is in many ways as sophisticated as many satellites which are being flown by other countries. For example, the satellite employs more than 12,000 active and passive electronic components in addition to 20,000 solar cells and other structural parts. There are more than 25,000 interconnections within the satellite; the total length of all connecting wires exceeds 6 km. In fact, this is the first satellite which has used, on a large scale, the low power Cosmos integrated circuits.

Precisely what have we learnt from the first satellite and how is it going to be helpful in our programme? We have achieved the technology of design and fabrication of a completely space-worthy satellite which includes structural design, fabrication and testing, thermal and power control systems, stabilisation and attitude sensor systems. We have established our ability to transmit complicated data from the satellite to the ground, receive and process the data on the ground, command the satellite from the ground and perform essential functions on the satellite. A complete tracking network to enable us to track the exact position and velocity coordinates of the satellite has been set up. We have developed competence in the fields of orbital predictions and quality control. A firm base has thus been established with which it is now possible to design and fabricate application technology satellites.

Encouraged by the success achieved through *Aryabhata*, an agreement to launch a second satellite from USSR was signed two days after the successful launch of the first. This will be an application technology satellite called SEO (Satellite for Earth Observations) which is scheduled to be launched before the end of 1978. SEO has been designed primarily to carry out earth observations of relevance to Indian needs, and will have two TV cameras and three microwave radiometers. The TV cameras will provide pictures over India, each picture covering an area of about 340×340 km with a resolution of 1 km^2. Photographs will be taken in two spectral bands, one in the visible (0·54 to 0·66 microns) and the other in the near infrared (0·75 to 0·85 microns). The microwave radiometer system (SAMIR) consists of a two frequency Dickie type radiometer operating at 19·35 GHz and 22·235 GHz. SAMIR will detect the fluctuations of microwave radiations mainly from the sea surface; these fluctuations will carry the signature of the sea state and surface temperature. The detection is in terms of a brightness temperature with a resolution typically of the order of 1°K. The data from these primary payloads will enable studies in the area of earth resources especially related to hydrology, forestry, oceanography and meteorology.

Besides, SEO plans to realise a set of secondary objectives that include the space qualification of indigenously developed thermal paints, heat pipe and solar cells. Studies in cosmic x-rays and conducting data collection platform experiments of relevance to meteorology also form other secondary objectives of SEO. The remote meteorological data collection will be carried out with about 10-12 platforms mainly distributed over inaccessible regions.

The satellite mainframe of SEO uses the results of the developmental efforts on

Aryabhata to a considerable extent. These include utilisation of the same structural design procedures, thermal control system, low bit rate telemetry system as well as attitude control and sensing system. The primary difference is mainly in the payload to carry out spin-axis control operations, which did not exist in *Aryabhata*. Planning the SEO configuration in this fashion has enabled considerable saving in time and in the overall cost of the project.

The successful launch and conduct of the proposed experiments with SEO will be a major milestone in the realisation of ISRO's goals with the primary emphasis on the communication and remote sensing applications.

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Plate 1

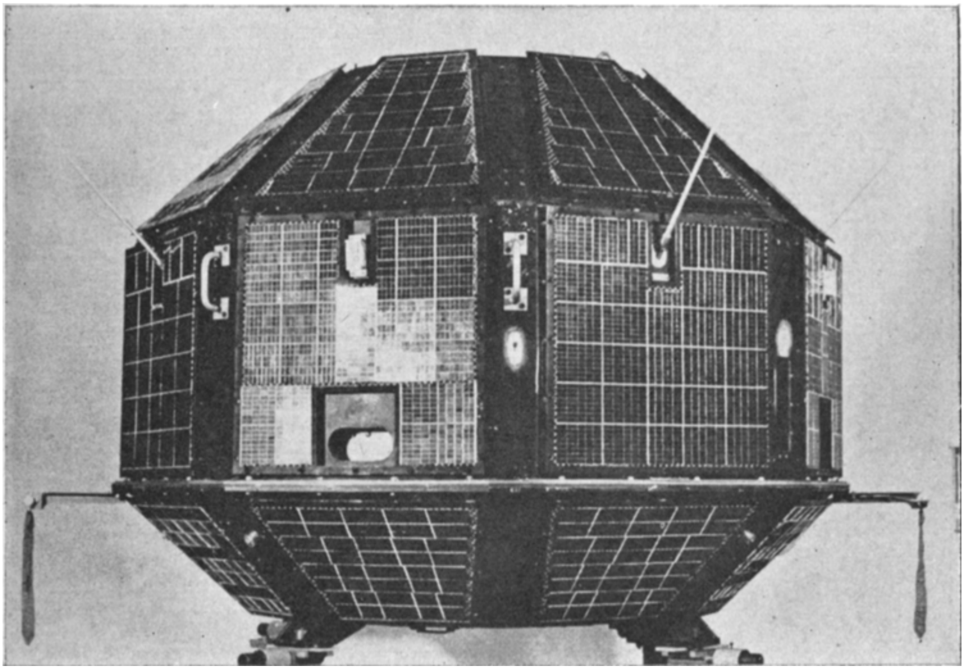

Figure 1. Photograph of *Aryabhata*

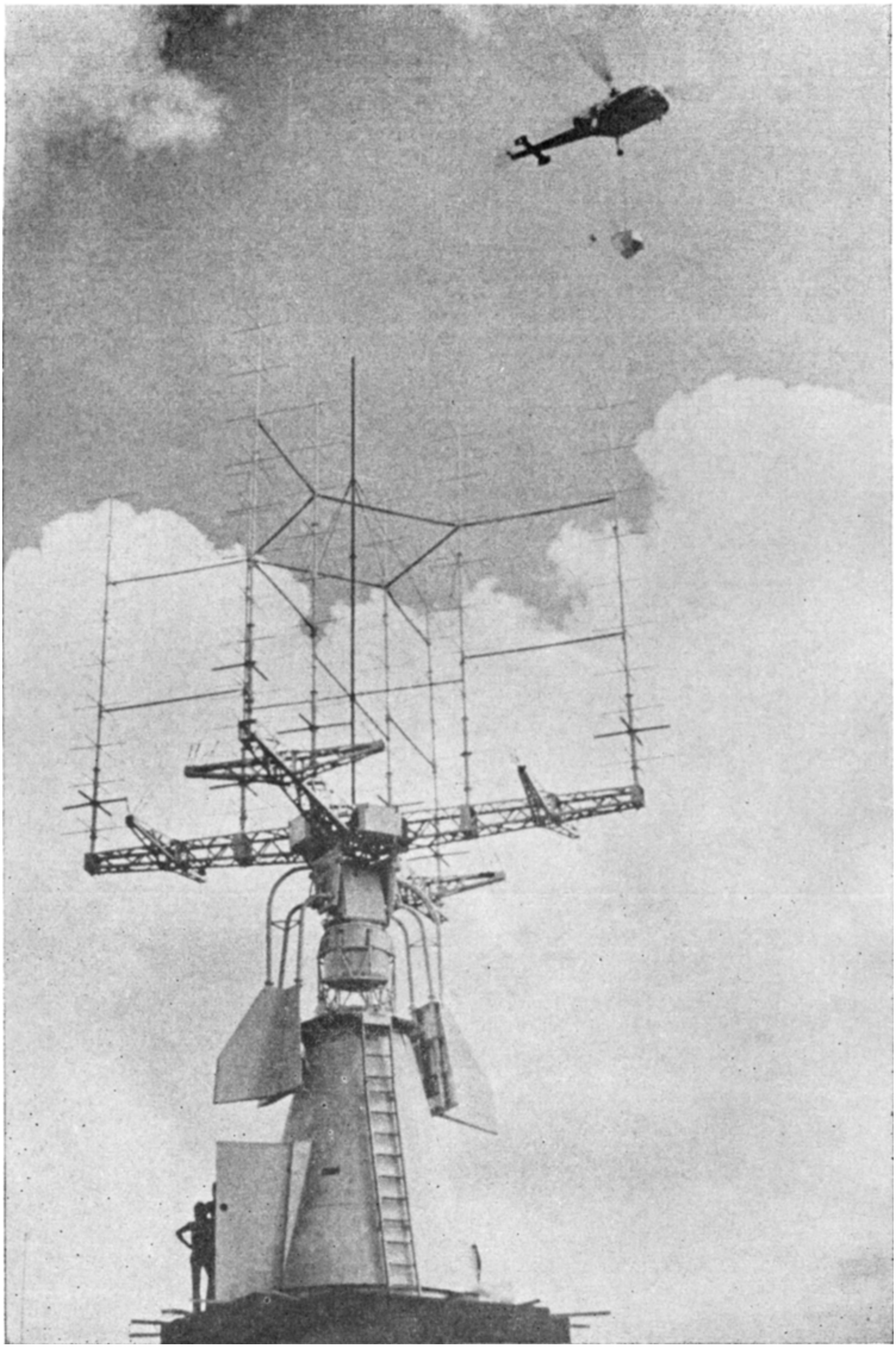

Figure 2. Photograph showing the configuration of the ground station at Sriharikota

Plate 3

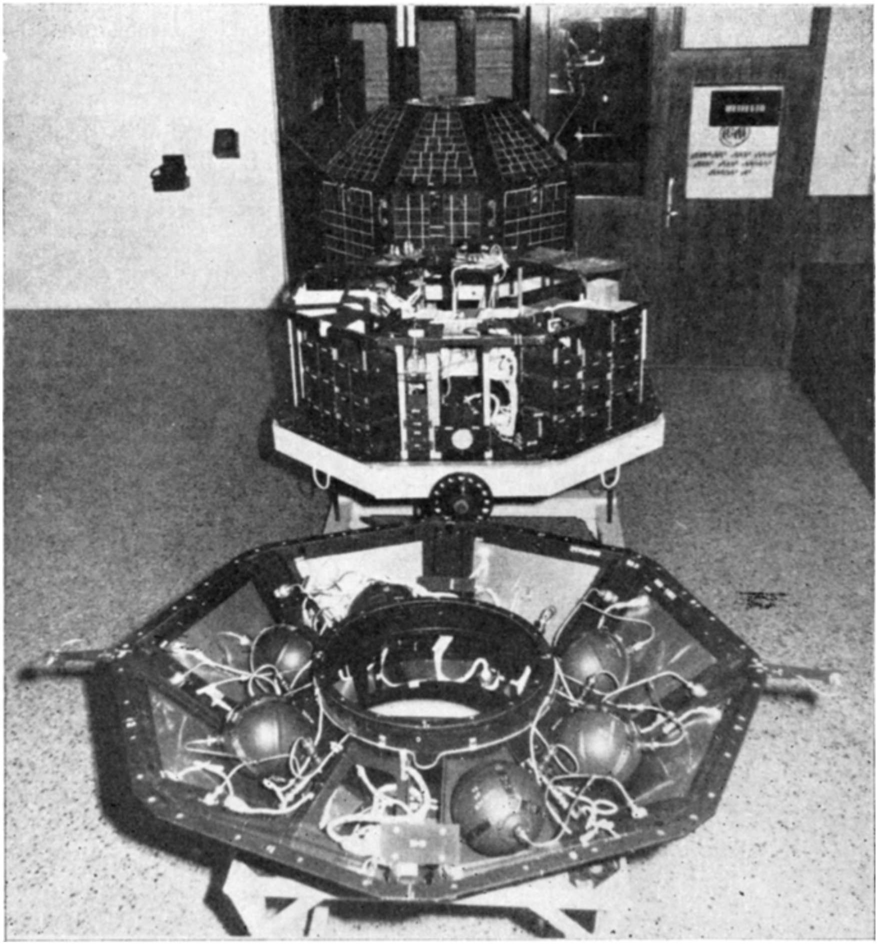

Figure 3. Photograph showing *Aryabhata* in the dis-assembled form